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**Language processing in neuro-degenerative diseases: semantic, phonological, and grammatical impairments in Alzheimer's disease, Parkinson's disease, and Frontotemporal Lobar Degeneration**  
**A linguistic overview**

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## **Introduction**

Language impairments in neuro-degenerative diseases gradually progress in the course of various mental breakdown processes and can be considered early markers (Berisha et al., 2015) and general features of particular dementia syndromes (Tang-Wai and Graham, 2008). Nevertheless, there is no standardised diagnostic material for tracing language impairments in dementia, and the number of clinical studies in which dementia-induced language impairments have been considered is scarce (Mahendra and Arkin, 2003).

In this paper, the results of linguistic studies in three major neuro-degenerative diseases, namely AD, PD, and FTLD will be discussed. The main aim of this article is to offer an overview of the different linguistic impairments in each syndrome, and of the impact of cognitive decline on language processing.

## **Method**

The electronic PubMed database was used for this paper. Because of its large variety of articles, no additional database was explored. We focused our search on linguistic research between January 2000 and December 2016, using the following keywords: Alzheimer's disease, Parkinson's disease, primary progressive aphasia, non-fluent progressive aphasia, fluent-progressive aphasia, semantic dementia, logopenic progressive aphasia, (behavioural/executive variant of) frontotemporal dementia in combination with terms like semantic, phonological, grammatical, verbs, nouns, sentences, naming and comprehension. We excluded articles under the following criteria: articles published in journals without peer review status, articles concerning therapy (e.g. deep brain stimulation, medical drugs etc.), articles not written in English, duplicates, and articles without a linguistic focus. Articles from before the year 2000 were only added occasionally to illuminate particular research domains in which insufficient current research results were found. Due to the large amount of literature, and in order to gain a general view on this extensive topic, we focused

on the qualitative description of the main research results in these research areas, instead of carrying out a quantitative analysis of the literature.

## **2. Alzheimer's Disease**

Language impairments in early stages of AD have been demonstrated in several experimental studies (e.g. Schröder et al., 2010). It has been suggested that, in addition to a decline in several other cognitive functions, primary or secondary language impairments can be considered pre-clinical markers of AD (Berisha et al., 2015) and may be among the main clinical symptoms of Alzheimer's disease (McKhann, et al., 2011). Analyses of language impairments can, therefore, contribute to the diagnosis of AD (Pekkala, 2013), to the differentiation between AD and normal ageing (Johnson et al., 2003), between AD and aphasia after a stroke (Mathews et al., 1994), and between different types of dementia (Mendez et al., 2003).

### **Phonological processing in AD**

The phonological level is traditionally assumed to be relatively unimpaired in early stages of AD (Azuma and Bayles, 1997). This has been demonstrated in studies in which narrative speech (Prins et al., 2002), naming (Hodges et al., 1991), repetition (Grossman et al., 1996), and reading (Lambon Ralph et al., 1995) was analysed.

Croot et al. (2000), however, point out that some AD patients do show phonological and articulatory problems in conversational speech, single-word production (naming, repetition, or reading), and in speech strings (counting, the alphabet, or 'calendar skills'). They studied a group of patients with AD and language impairments, and stressed that AD is a heterogeneous syndrome in which phonological and articulatory disabilities are the result of an atypical distribution of pathological deviations in the brain. More evidence of phonological impairments in AD was found in a test on word repetition (Glosser et al., 1997), on the processing of non-words (Glosser et al., 1998), and when the patients had access to phonological representations in object naming (Faust et al. 2004). Results of a sentence repetition task revealed additionally that AD patients produce more phonemic paraphasias than controls (Biassou et al., 1995).

### **Lexical-semantic processing in AD**

A pathological breakdown of semantic memory may happen in early stages of AD (Gold and Budson, 2008) and is associated with the beginning of word-finding and comprehension difficulties. These increasing deficits are among the first detectable language impairments of AD (Rogers et al., 2006) and can either be considered the result of a loss of semantic content, information, or knowledge

stored in semantic representations (Flanagan et al., 2013), or as the consequence of an inability to access intact semantic representations (Venneri et al., 2008). Combinations of these phenomena have been described as well (Rogers and Friedman, 2008). Word frequency and age of acquisition play a role in single-word recognition (Balota et al., 2002), object recognition (Holmes et al., 2006), single-word comprehension (Cuetos et al., 2010), and in word retrieval (Cuetos et al., 2008; Rodríguez-Ferreiro et al., 2009) in AD, which supports the idea that there is an enduring reciprocal link between semantic and episodic memory (Small and Sandhu, 2008). Furthermore, there seems to be no difference for AD patients between performing verbal or visual versions of single-word comprehension and production tasks (Rogers et al., 2006).

### *Word comprehension*

The breakdown of semantic knowledge in comprehension processes in AD is examined in early studies (e.g. Grossman and Mickanin, 1994). Martin and Fedio (1983) argue that AD patients have particular problems differentiating items of the same semantic category, whereas broader categorical information remains relatively preserved. Further evidence of category-specific comprehension deficits in AD is revealed by Silveri et al. (1991), who showed that AD patients perform worse with living than with non-living items. Comparable results for other semantic domains are shown by Harciarek and Kertesz (2009). Masterson et al. (2007) also found word comprehension deficits but no grammatical class effects in AD and argued that the patients' performance might be affected by semantic relatedness and not by category-specific impairments. In line with Zannino et al. (2006), they claim that mild category-specific impairments in experimental situations are often related to semantic density in specific semantic domains.

### *Word production*

Word production deficits are traditionally detected using naming studies. Visch-Brink et al. (2004) revealed a complex naming pattern for AD patients. For some AD patients object naming turned out to be preserved in combination with impaired visual and verbal semantic processing, whereas another group of AD patients showed preserved verbal-semantic processing and impaired object-naming skills. Visch-Brink et al. (2004) therefore assume a direct visuo-phonological pathway for picture naming that passes through the semantic system, as well as the existence of a multiple semantic representation system with separate visual and verbal semantics. This assumption requires further support by other studies.

Research on both object and action naming shows contradictory outcomes, which presumably have methodological or language-specific reasons: In some studies object naming is better preserved

than action naming (Kim and Thompson, 2004; Druks et al., 2006; Masterson et al., 2007), whereas in other studies the opposite pattern is reported (Robinson et al., 1999, Parris and Weekes, 2001), or no difference is found at all (Lee et al., 1998; Parris and Weekes, 2006). Kim and Thompson (2003) argue that, despite these contrary results, the same semantic knowledge breakdown patterns can be observed in noun and verb processing. Verma and Howard (2012), moreover, claim that naming impairments in AD can serve as a marker for primary lexical-semantic memory impairments rather than for an overall cognitive decline.

### **Grammatical processing in Alzheimer's disease**

#### *Sentence comprehension*

Until a few decades ago, sentence comprehension was thought to be preserved in AD (Smith, 1989). As from the mid-1990s, however, sentence comprehension impairments in AD have been described as well (e.g. Croot et al., 1999).

Sentence comprehension – more specifically, syntactic complexity – is assumed to interfere with working memory impairments in AD (Almor et al., 2001). Since increasing sentence complexity usually leads to increased sentence length, more information has to be stored and encoded. This requires a larger working memory capacity. Grossman et al. (1996) reported a relation between sentence length and comprehension skills, and in a later study, an additional influence of limited working memory capacity, impaired cognitive resources, and semantic aspects in sentence processing were found (Grossman and Devine, 1998), leading to the conclusion that sentence comprehension deficits in AD are multi-factorial in nature. Rochon et al. (1994), however, argue that not syntactic complexity but the number of prepositions in a sentence and 'post-interpretative processing' influence sentence comprehension in AD. Grober and Bang (1995) go even further and consider sentence comprehension problems to be a genuine grammatical deficit not influenced by co-existing semantic impairments or working-memory problems. Kavé and Levy (2003), who studied verb inflection in AD, do not share this view. They tested Hebrew-speaking AD patients with an off-line grammaticality-judgement task, and no morpho-syntactic impairments for the variables gender, person, or tense were revealed. Such contrasting outcomes can be the result of methodological diversity in the tests on grammatical processing in AD, with which different grammatical structures, sentence length and languages were analysed.

#### *Sentence production*

Syntax was initially presumed to be well formed, grammatically diverse and preserved in AD (Kemper et al., 1993). Further research on sentence production and on the semantic, executive and

morpho-syntactic complexity of verbs, however, revealed contradictory results. Altmann (2004), for instance, showed that AD patients produce fewer correct responses as well as deviating proportions of active and passive sentences than NBDs, as a result of an inability to fully activate semantic representations. Kim and Thompson (2004) revealed verb production impairments in AD and argued that the observed deficits are the consequence of a lexical-semantic breakdown. Further evidence for the existence of verb deficits in AD is given by Fyndanis et al. (2013). Their Greek AD patients had more difficulties with aspect and tense, compared to agreement. Fyndanis and colleagues argue that agreement demands isolated, grammatical processing, whereas aspect and tense involve processing and integration of grammatical with extra-linguistic/conceptual information, causing additional executive demands. Morpho-syntactic deficits, such as verb-tense errors and verb-argument-structure errors, were found in English conversational speech of AD patients by Altman et al. (2001). These results, however, are not in line with the outcome of a study made by Kaprinis and Stavrakaki (2007), who reported that morpho-syntactic abilities are preserved in mild to moderate AD in Greek narrative speech. Such contrasting outcomes may, again, result from differences in the morphological structures of the languages (Altmann and McClung, 2008).

### **3. Parkinson's disease**

Approximately 25 percent of the Parkinson population suffer from cognitive decline at the time of their diagnosis. Several studies have shown that in PD, disorders of working memory (Cools et al, 2009), word sequencing (Fama and Sullivan, 2002), and attention-set shifting (Ravizza and Ciranni, 2002) are prominent. This leads to the assumption that language processing in Parkinson's disease could indirectly be influenced by cognitive impairments, which in turn cause secondary language impairments (Bastiaanse and Leenders, 2009).

#### **Phonological processing in Parkinson's disease**

Literature on phonological processing in PD is comparatively scarce. Early research results on prosody in both comprehension and production showed impairments, but were associated with cognitive deficits and speech impairments rather than with linguistic deficits (Lloyd, 1999). In their review article on language production, Altmann and Troche (2011) argue that phonemic paraphasias are difficult to distinguish because of the hypokinetic dysarthria often present in PD.

Elorriaga-Santiago et al. (2013) reported deficits in patients with PD across several sub-components of phonological processing, and stressed that these results were independent of executive resources such as attention and working memory. While no causal interaction between malfunctioning phonological processing and verbal language comprehension was present,

correlations between phonological skills and reading comprehension abilities could be revealed. In a study by Zanini et al. (2010), in which the narrative speech of bilingual patients with PD was analysed, more phonemic paraphasias were detected in L1 than in L2. In this study, the authors suggest that implicit language processing, which proceeds without making demands on central attentional resources, is impaired in PD. Implicit learning and implicit memory processing, as in L1, are affiliated with biological substrates of the brain, such as the basal ganglia. Explicit learning, on the contrary, is associated with declarative memory processes and other parts of the brain. Impairments of the basal ganglia will consequently lead to impairments of L1. As the basal ganglia are thought to play a role in phonological processing, Zanini et al. (2010) found a way to combine and explain these two phenomena.

### **Lexical semantic processing in Parkinson's disease**

#### *Word comprehension*

Lexical-semantic processing is assumed to be impaired in PD (Angwin et al., 2009) and is related to cognitive impairments (Copland et al., 2009). The extent of dopamine reduction seems to have an influence on this process (Angwin et al., 2006). The performances of PD patients in a lexical-decision task, for instance, revealed different results in OFF and ON levodopa medication situations (Angwin, 2009). More evidence of the interaction between dopamine and lexical-semantic processing in PD is offered by Boulenger et al. (2008). They analysed priming effects in a lexical decision task for action verbs and concrete nouns in PD in ON and OFF levodopa treatment situations, and compared the findings to the results of NBDs. The priming effect for action verbs increased with the use of levodopa. These results were not found for nouns. In an EEG study with PD patients, De Letter et al. (2012) revealed that the intake of levodopa medication led to higher current densities for the semantic perception of hand-action words in several brain regions associated with limb-motor activation, semantic-phonological processing, and reading comprehension. Fernandino et al. (2013a) also showed evidence for a sensibility for action verbs in PD. In a lexical decision task and a semantic similarity judgement task for action and abstract verbs, performance was poorer when action verbs were processed. These studies are based on the assumption that the semantic processing of action words involves the same cortical motor regions that are involved in the planning and execution of the related body movements (Klepp et al., 2014). Kemmerer et al. (2013), however, could not confirm these results. In their study the comprehension of action verbs and non-action verbs in PD and NBDs were tested by analysing the accuracy and reaction times in ON and OFF medication situations. The authors found no differences between accuracy performances, regardless of whether the PD patients were ON or OFF their medication.

### *Word production*

Herrera and Cuetos (2012) studied reaction times ON and OFF medication using an action-naming task. The verbs they used had either a high or a low degree of motor content. PD patients OFF medication were slower to name actions with a high motor content than PD patients ON medication. The authors, therefore, argue that there is a relationship between dopamine, motor brain areas, and verb production. Herrera et al. (2012) came to a comparable conclusion, also using an action-naming task. The actions they analysed were divided into the same two categories: actions with high or low motor content. PD patients showed more impairment naming the first.

Dopamine fluctuations additionally seem to cause grammatical class dissociation. Herrera and Cuetos (2013) studied the lexico-semantic performance of PD patients ON and OFF medication using a noun and verb association task. Their most noticeable result was that PD patients produced fewer words in response to verbs in an OFF medication situation whereas medication had no influence on the production of nouns. This outcome, again, suggests that there is an interaction between dopamine and verb production, and that the motor system is activated in action-language processing.

## **Grammatical processing in Parkinson's disease**

### *Sentence comprehension*

Sentence comprehension in PD is impaired and is caused by several factors. Lieberman et al. (1992) pointed at the causality between comprehension impairments and cognitive decline in PD. Compared to NBDs, they found a difference between PD patients with cognitive impairments and those without. More complex sentences were harder to process for PD patients with cognitive impairments. Executive function disorders responsible for comprehension problems of grammatically complex sentences in PD are attention resource limitations (Lee et al., 2003), impaired working memory (Grossman et al., 2001)<sup>1</sup>, reduced processing speed (Angwin, 2005), disturbed cognitive set-switching, and decline in complex sequencing abilities (Colman et al., 2006). The shortage of dopamine in PD leads to a reduction of executive resources, contributing to these sentence comprehension deficits (Grossman et al., 2001).

The affected motor system in PD is, as described in the previous paragraph, additionally associated with impaired semantic processing. Fernandino et al. (2013b), for instance, found that in PD, the comprehension of sentences with action verbs is more impaired than the comprehension of sentences containing abstract verbs.

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<sup>1</sup> Please note that in a study of Skeel and colleagues (2001) sentence comprehension problems in PD were found, but no deficits in working memory could be revealed.



### *Sentence production*

Empirical data about verb production in PD reveal conflicting outcomes. Ullmann et al. (1997) focussed on the differences between regular and irregular verbs and demonstrated that PD patients have less difficulty producing irregular past tense forms than regular past tense forms, both for existing and for novel verbs. Ullmann and colleagues argue that rule-based grammatical processing (needed for regular verbs) is reduced in PD patients, who suffer from impairments of the left basal ganglia. Inflection of irregular verbs is retrieved from the lexicon, as a part of the declarative memory system, which is not impaired in PD. Macoir et al. (2013) found no differences between regular and irregular verbs and claim that the basal ganglia play a role in language processing, but are not specifically involved in verb production. However, there may be a language-specific issue at stake here. Ullman and colleagues tested in English, with verbs that are truly irregular, whereas Macoir and colleagues tested in French, where 'irregular' verbs have a deviant but still quite regular pattern.

Research on sentence production sheds a light on the cognitive nature of verb processing impairments in PD. Colman et al. (2009) used a verb production task and demonstrated that it is not linguistic complexity, but rather sentence length, working memory, and set switching that play decisive roles in verb production problems in a sentence context. Switching problems and involvement of the basal ganglia in non-linguistic processes involving the generation of verbs in PD are also described by Crescentini et al. (2008).

## **4. Frontotemporal lobar degeneration**

In 1982, Mesulam described a set of patients with "slowly progressive aphasia", a term which would later be renamed to Primary Progressive Aphasia, or PPA (Mesulam and Weintraub, 1992). PPA refers to a group of neuro-degenerative diseases in which isolated language disorders cannot be explained as the result of post-stroke damage, but are the consequence of a focal form of atrophy in the frontotemporal areas of the brain. These are in a state of slow deterioration, with an absence of problems during every-day life in the first years after the first apparent language changes (Gorno-Tempini et al., 2011). Mesulam (1982) defined a fluent variant – semantic dementia (fvPPA) – and a non-fluent variant – progressive non-fluent aphasia (nfvPPA). Gorno-Tempini et al. (2004) were the first to describe the logopenic variant of primary progressive aphasia (lvPPA), the third variant of PPA. Finally, there is the behavioural variant of frontotemporal lobar degeneration (bvFTD).

#### **4.1.1 Progressive non-fluent aphasia**

NfvPPA is characterised by agrammatism in language production, effortful halting speech with inconsistent sound errors and distortions (apraxia of speech), impaired comprehension of syntactically complex sentences, yet spared single-word comprehension and spared object knowledge (Gorno-Tempini et al., 2011).

#### **Phonological processing in nvfPPA**

The distinction between apraxia of speech, one of the possible core features of nvfPPA (Gorno-Tempini et al., 2004), and phonological impairment has been discussed in several nvfPPA studies and is not quite clear. Josephs et al. (2006) claim that the term ‘phonemic paraphasia’ in nvfPPA is ‘a misnomer’. They emphasize that the term should not be associated with nvfPPA and is probably used to refer to phonetic and not to phonemic or phonological deficits. Ash et al. (2010), on the contrary, report that 82% of all speech errors in a narrative task have a phonemic source, which is inconsistent with apraxia of speech. Naming and paraphasic errors in nvfPPA have generally been affiliated with phonemic and phonological processing disorders, in which phonological encoding processes are assumed to be impaired (Mack et al., 2013).

#### **Lexical-semantic processing in nvfPPA**

##### *Single-word comprehension*

According to Gorno-Tempini et al. (2011), single-word comprehension as well as knowledge of objects is relatively well preserved in the early stages of the disease. Rhee et al. (2001), however, used a spoken word-to-picture-matching task to show that nvfPPA patients have verb-comprehension problems. Bak (2000), who differentiated between the processing of verbs and of nouns, showed that patients with nvfPPA have increasing problems with the semantics of verbs as opposed to nouns. These subtle semantic processing deficits in nvfPPA are explained as the consequence of limited executive resources (Peelle and Grossman, 2008). Harciarek and Kertesz (2009) also found single-word comprehension difficulties in nvfPPA, in a longitudinal study in which only objects were assessed, and they noticed that even category-specific comprehension deficits may exist.

##### *Word production*

In nvfPPA, paraphasic errors in word production are presumed to be more phonological than semantic in nature (Croot et al., 1998), and impaired phonological encoding underlies object

naming deficits and anomia (Mack et al., 2013). Subtle semantic mapping impairments during object naming in nvPPA have been observed as well (Thompson et al., 2012a).

In line with the observation of Gorno-Tempini et al. (2011) that knowledge of objects is relatively well preserved, Silveri and Ciccarella (2007) found that action naming is more impaired than object naming, and argued that both linguistic and executive deficits play a role in grammatical class dissociation. In a case study of a woman with nvPPA (Hillis et al., 2002), the oral naming of actions showed an earlier decline than the written naming of actions, or the oral and written naming of objects. Comprehension of these verbs and nouns remained relatively intact. Hillis and colleagues (2004) mentioned comparable results in a study with more patients. Thompson et al. (2012b) also found that nvPPA patients have more difficulties naming actions than objects, whereas, again, no comprehension impairment of these word classes could be revealed.

### **Grammatical processing in nvPPA**

Patients with nvPPA show increasing problems with grammatical processing over the course of the disease. The decline of verb semantics (relative to noun semantics) influences the sentence level and has a considerable impact on the production of narrative speech.

#### *Sentence comprehension*

Sentence comprehension in patients with nvPPA is impaired (Charles et al., 2014). Limited auditory verbal short-term memory capacities seem to influence grammatical and phonological processing during sentence comprehension (Peelle et al., 2008). Most of this research is based on comparing the comprehension of simple sentences containing subject-verb-object structures, and complex sentences containing subject-relative or object-relative embedded clauses.

#### *Sentence production*

Sentence production in nvPPA is characterised by slow and effortful speech (Thompson et al., 1997), a reduced speech rate (Rogalski et al., 2011), reduced speech fluency (Gunawardena et al., 2010), phonemic problems (Wilson et al., 2010), grammatical errors (Thompson et al., 2012b), word-retrieval difficulties causing hesitations and pauses (Ash et al., 2010), impaired prosody and speech-sound errors provoked by dysarthric and / or apraxic speech (Josephs et al., 2006), and the production of agrammatic speech (Weintraub et al., 2009).

Agrammatic speech in nvPPA is caused by a lack of verbs (Hillis et al., 2002), a relatively small proportion of grammatical sentences, impaired production of verb inflection, as well as a lack of complex embedded structures and simple verb-argument structures (Wilson et al., 2014).

#### **4.1.2 Semantic dementia / fluent or semantic variant of PPA (fvPPA)**

FvPPA is the result of the deterioration of semantic memory, leading to a gradual decrease in conceptual knowledge (Neary et al., 1998). Word comprehension deficits (Harciarek and Kertesz, 2009) and a salient shortage of content in language production are the consequences of this pure semantic impairment. The phenomenon of this semantic degeneration process is caused by the loss of semantic representations rather than reduced access or insufficient retrieval of semantic information. The term 'semantic dementia' is traditionally used to refer to a syndrome in which both verbal and non-verbal semantic conceptual information is impaired, whereas 'semantic or fluent variant of primary progressive aphasia' is related to isolated language deficits due to the loss of semantic memory. As Adlam et al. (2006) showed that non-verbal deficits in fvPPA can be revealed as well, no further distinction between these two terms will be made in this paper.

#### **Phonological processing in fvPPA**

Phonological processing is assumed to be preserved in fvPPA until the late stages of the disease (Macoir et al., 2015). In narrative speech and in confrontation-naming tasks, phonological paraphasias are generally absent.

#### **Lexical-semantic processing in fvPPA**

##### *Word comprehension*

There is a wide range of word comprehension deficits in fvPPA. Bozeat et al. (2000), for instance, compared verbal and non-verbal comprehension impairments and found that fvPPA patients had more difficulties with sound-to-picture-matching and verbal association than with word-to-picture matching and pictorial semantic association. The authors of this study argue that, compared to pictures, sounds and words have a relatively arbitrary relationship with their meaning, making them more vulnerable to degradation in fvPPA. Bak and Hodges (2003) were interested in verbal and non-verbal comprehension performances in different grammatical classes. They used a verbal and a visual form of the Pyramids and Palm Trees Test and the Kissing and Dancing Test, which are association tasks for objects and actions. The authors showed that patients with fvPPA have more difficulties with the Pyramids and Palm Trees Test than with the Kissing and Dancing Test, but only for the respective verbal part. In line with these outcomes, Macoir et al. (2015) showed that combining adjectives with object nouns in fvPPA is impaired, whereas isolated knowledge of adjectives is unimpaired. Macoir et al. (2015) suggest that the binding of different modality-specific properties of objects, which needs activation when adjectives are associated with nouns, is disrupted in fvPPA. In contrast with these findings, Yi et al. (2007) and Rhee et al. (2001) found that fvPPA patients have more problems with the comprehension of verbs compared to nouns. The last

mentioned authors assumed that these deficits can be correlated with the breakdown of semantic feature knowledge, as the semantic network of verbs is not organized in as finely grained a way as the semantic network for nouns (Yi et al., 2007).

### *Word production*

Category-specific impairments are often described in fvPPA. The degradation of visuo-perceptual information in fvPPA is thought to play a role in such category-specific impairments (Lambon Ralph et al., 2003). Relatively impaired performance in particular domains of knowledge has been reported in case as well as group studies, with living things spared (Zannino et al., 2006) or impaired (Lambon Ralph et al., 1998). In a large two-year follow-up group study by Merck et al. (2013), a relative preservation of the semantic categories “fruit” and “vegetables” is reported.

Coccia and colleagues (2004), who compared object use and object naming in fvPPA, found support for the assumption that the semantic memory is amodal. These authors show that fvPPA patients have problems naming objects in the early stages of their disease, whereas the use of these objects stays relatively well preserved. Their study also demonstrates that participants show better naming performance when naming objects while demonstrating their use, compared to naming the same objects in isolation.

Evidence for grammatical class dissociation in fvPPA is offered in several studies. Hillis and colleagues (2004) showed that object naming is more impaired in fvPPA than action naming (Hillis et al., 2004; 2006). The same pattern is observed by Thompson and colleagues (2012b) and by Silveri and Cicarelli (2007).

## **Grammatical processing in fvPPA**

### *Sentence comprehension*

The structural parts of sentence processing are relatively well preserved in fvPPA (Grossman et al., 2005). Rochon et al. (2004) followed a woman with fvPPA for five years. Her sentence comprehension skills remained largely intact over this period, but were influenced by the loss of semantic content, leading to increasingly worse performance in a sentence-comprehension task. Comparable results were described by Grossman and Moore (2005).

In later stages of fvPPA syntactic and morphological processing deficits slowly become more apparent (Bright et al., 2008).

### *Sentence production*

Grammatical processing remains relatively unimpaired until later stages of fvPPA (Kavé et al., 2007). Syntactic information at word level, such as mass/count distinction or information about argument structure is still available, whereas semantic or lexical content is already absent (Breedin and Saffran, 1999). Subtle grammatical deficits, however, can be observed as fvPPA progresses. These impairments are probably connected to the degeneration of lexical-semantic or conceptual representations, as shown with comprehension (Rochon et al., 2004) as well as production tasks (Wilson et al., 2010). Syntactic processing itself, though, remains relatively unimpaired (Wilson et al., 2012).

Bird et al. (2000) followed a group of fvPPA patients using the Cookie Theft Picture. During the course of the disease, the use of nouns showed an earlier decline than the use of verbs. The authors argue that the degradation of conceptual knowledge in fvPPA has a negative influence on low frequency words. The progression of fvPPA is assumed to lead to reduced grammatical complexity and paragrammatic errors in narrative speech in later stages of the disease (Wilson et al., 2010).

#### **4.1.3 Logopenic progressive aphasia**

The most recently identified variant of primary progressive aphasia is called logopenic or phonological primary progressive aphasia, or the logopenic version of Primary Progressive Aphasia (lvPPA). LvPPA is most commonly affiliated with AD pathology (Rohrer et al., 2012). Among different language disturbance symptoms, anomia is the most noticeable and prominent feature of LPA.

#### **Phonological processing in lvPPA**

Central to lvPPA are phonological loop dysfunctions (Gorno-Tempini et al., 2008), resulting in poor performance in tasks that test the (phonological) working memory, such as digit-span tasks or sentence repetition. A specific feature of lvPPA is a phrase- and sentence-repetition disorder. Phonological rather than semantic impairments are assumed to play a role here (Henry and Gorno-Tempini, 2010). Phonological errors are also observed in other tasks, such as reading non-words and irregular words, and in naming (Petroi et al., 2014). Mack et al. (2013) focused on phonological errors in object-naming performance, and compared lvPPA and nvfPPA patients. They claim that impaired phonological processing may contribute to anomia in both lvPPA and nvfPPA, showing that phonological encoding is impaired in nvfPPA only, and that phonological deficits in lvPPA seem to reflect impairments of phonological word form retrieval.

Phonological errors have been observed at the word and sentence level and in narrative speech. For this reason, phonological errors are thought to be highly predictive clinical markers for lvPPA

(Leyton et al., 2014), although some authors, on the other hand, argue that the prevalence of those errors should not be considered a core feature of lvPPA (Petroi et al., 2014).

In some patients with LPA, apraxia of speech has been observed as well (Croot et al., 2012). Croot and colleagues (2012) compared the data from nvPPA and lvPPA patients in which both apraxia of speech and phonological errors were found. Therefore, these characteristics alone are not differentiating features between nvPPA and lvPPA. The ratios of apraxia of speech and phonological errors, however, showed a high sensitivity in the clinical differentiation between the two syndromes.

### **Lexical-semantic processing in lvPPA**

#### *Word comprehension and word production*

Single-word comprehension as well as object knowledge is preserved in the early stages of lvPPA (Gorno-Tempini et al., 2011), but a decline over time has been observed (Faria et al., 2014). No specific word-class deficits in the comprehension and production of verbs and nouns were found (Thompson et al., 2012a).

Anomia is a common feature in lvPPA (Leyton et al., 2014), at word and sentence levels and in narrative speech. Naming disorders in lvPPA are not associated with semantic but with lexical retrieval and phonological deficits (Henry and Gorno-Tempini, 2010). The assumption that naming disorders in lvPPA have no semantic basis is somehow remarkable, considering that Alzheimer pathology is involved in lvPPA. Subtle lexical-semantic impairments, however, appear in several experiments (e.g. Thompson et al., 2012a) and are assumed to contribute to anomia in lvPPA.

### **Grammatical processing in lvPPA**

#### *Sentence comprehension*

Comprehension deficits of simple passives and complex structures in lvPPA are interpreted as the product of a short-term phonological memory deficit, not as a grammatical impairment (Gorno-Tempini et al., 2004). Increasing auditory attention deficits seem to have an additional influence on sentence-comprehension abilities in lvPPA (Etcheverry et al. 2012). In opposition to the assumptions from Gorno-Tempini et al (2004), Zimmerer et al. (2014) reported the case of a man with lvPPA who had more problems understanding active sentence constructions than passive constructions, and could not rule out the possibility that there are grammatical explanations for this phenomenon.

### *Sentence production*

Sentence production in lvPPA is characterized by slow speech, simple but accurate grammatical structures, and word-finding pauses (Gorno-Tempini et al., 2004), while inflection of verbs is considered to be preserved (Hilger et al., 2014). In contrast to these observations, Teichmann et al. (2013) found that 40 % of their lvPPA patients show grammatical impairments. In a review on inflectional morphology in primary progressive aphasia, Auclair-Oullet (2015) discusses the inconsistent methodology of these studies and claims that individual data on lvPPA do not confirm the assumption that verb morphology is unimpaired in this disease.

## **4.2 Frontotemporal dementia, the behavioural variant**

BvFTD leads to behavioural changes like apathy, hyperorality, the loss of sympathy/empathy, disinhibition, perseverative behaviour, and to a dysexecutive syndrome (Rascovsky et al., 2011). Language impairments are not among the core features of this syndrome, but cannot be completely ruled out.

### **Phonological processing in bvFTD**

In the early stages of bvFTD, phonological processing is presumed to be unimpaired (Chare et al., 2014). In the later stages of this syndrome, phonological errors can occur. In a case study of Tainturier et al. (2001), the language performance of a woman with advanced bvFTD is described. In the late stages of her disease this woman showed a relatively preserved written naming performance, despite a severe decline in her oral naming ability. The authors of this experimental study associate the described discrepancy with lexical and phonological processing deficits.

### **Lexical-semantic processing in bvFTD**

#### *Word comprehension and word production*

Rogers et al. (2006) analysed semantic processing in bvFTD, including naming, visual and verbal comprehension. The authors concluded that bvFTD only has a minor impact on the semantic system. Impairments in object naming, however, are described by Moore et al. (2003) and McCawley et al. (2005), who assume that impaired naming performances in FTD are related to a deficit in semantic memory. No clear category-specific semantic impairments could be distinguished in their naming tasks.

A direct action-object naming comparison revealed a selective action-naming impairment (d'Honinckhun and Pillon, 2008) due to executive resource limitations, rather than to lexical-semantic deficits. In a study by Bak and Hodges (2003), bvFTD patients again showed greater



difficulties processing verbs/actions than nouns/objects in the visual version of the Pyramids & Palm Tree and Kissing & Dancing tests.

### **Grammatical processing in bvFTD**

#### *Sentence comprehension, sentence production*

In the early stages of bvFTD, grammatical processing is relatively unimpaired. Sentence comprehension deficits are shown in several experimental studies (e.g. Peelle et al., 2008) and are associated with limitations of the working memory, as well as reduced attention vigilance, inhibitory control, sequencing ability, and thematic cohesion (Reilly et al., 2010). Limitations of switching control, also resulting in sentence-comprehension difficulties, are observed in bvFTD as well (Rhee et al., 2001).

## **5. Conclusion**

No consistency could be found across studies in the performance of demented speakers on language tasks, even when they are seemingly assessing the same behaviour, e.g. semantic knowledge. Phonological, semantic, and grammatical deficits can be observed in the early stages of nearly all neuro-degenerative diseases, but cannot be regarded as a consistent set of parameters that clearly differentiate between the separate syndromes. This linguistic division, furthermore, cannot be used to accurately describe the linguistic or cognitive sources of these impairments.

Analysing and describing the sources of these deficits – i.e. analysing both the linguistic and the executive properties – can help to distinguish between the above-mentioned impairments and diseases. The focus on further linguistic research in neuro-degenerative diseases should, therefore, not be on describing isolated and pure language disorders, but on analysing the degree, proportions, and nature of the linguistic and cognitive impairments. The presence or absence of linguistic impairments allow for specific assumptions about the stage and nature of the neuro-degenerative disease and accordingly about the presence of a primary, a secondary or a ‘mixed’ language disorder, in which both language and cognitive deficits lead to language impairments. The combination of the analysis of language processing, neuro-psychological assessment, and radiological diagnostics can – as proposed by Gorno-Tempini et al. (2011) and McKahnn et al. (2011) – be regarded as a powerful procedure for differentiating between the separate forms of dementia and other neuro-degenerative diseases.

Combining neuro-anatomical information with linguistic and cognitive impairments would have shed more light on central questions about causal connections in defining linguistic profiles in neuro-degenerative diseases in this paper. As the scope of describing and comparing all neuro-

anatomical backgrounds in the here mentioned neuro-degenerative diseases would have lead to a disproportionate size of this article and would have influenced our linguistic intensions analysing this topic, we abandoned the consideration including neuro-anatomical information in this paper and recommend it for further research. Another possibility for developing more reliable differentiation parameters is to concentrate on the processing of particular word classes, such as verbs and nouns, instead of focusing on isolated semantic, phonological, and grammatical impairments.

To improve future research on language processing in AD, PD, nvPPA, fvPPA, lvPPA, and bvFTD, longitudinal studies which include both cognitive performance and language processing should be conducted. In order to avoid fragmented reports or methodical complications, unified testing protocols for all patients with neuro-degenerative diseases are recommended. To our opinion unified testing protocols for clinical use (not exceeding 60-90 minutes in application time) and unified testing protocols for research use (with broader time investments) should be considered separately. Furthermore, recruiting patients with different degrees of cognitive decline within each group offers the opportunity to analyse to which extent cognitive impairments have an influence on the different stages of language processing. Verb processing seems to be the most informative source in such experimental research, as it comprises semantic, syntactic, and morphological aspects, and is driven by executive resources. Verb-processing experiments should therefore be analysed at word level, sentence level, and in narrative speech within the same group of patients. Object naming was involved in more than 95 % of the naming studies on neuro-degenerative diseases during the last few decades, whereas only 35 % included action naming. A screening documenting phonological deficits and/or apraxia of speech should also be included. Adding aphasic patients offers the opportunity to gain further insight into the linguistic impairments in certain neuro-degenerative diseases, or into the cognitive deficits in aphasic disorders. Designing follow-up studies with the same groups may make the progressive character of the aforementioned diseases more transparent, and theories about language processing in neuro-degenerative diseases methodologically more reliable.

Further research on profiles of linguistic impairments differentiating between neuro-degenerative diseases could lay in the construction of quantitative review research in which effect sizes and additional test variables in a wide and heterogeneous range of studies are considered.

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